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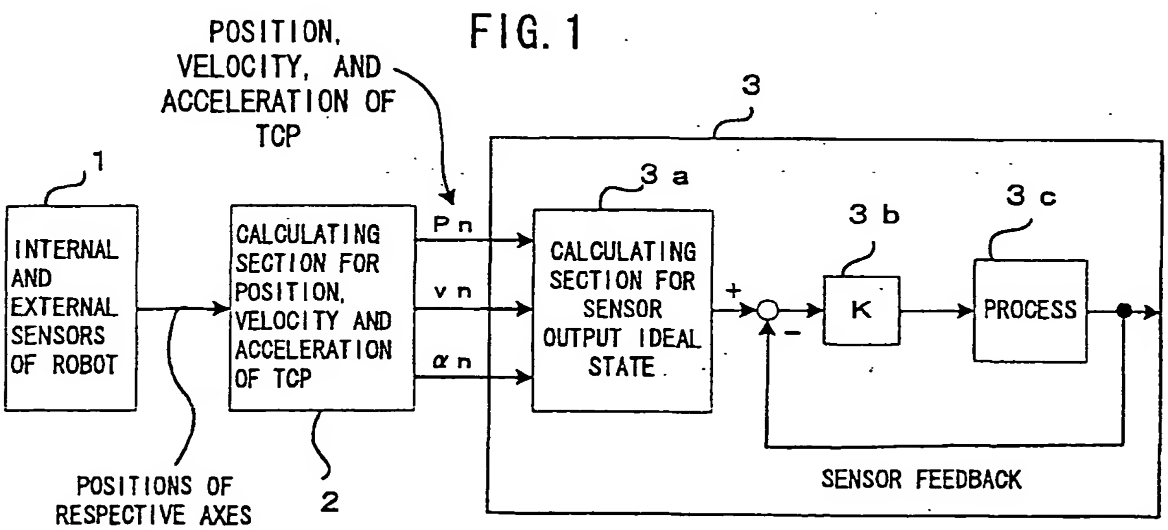
(54) **Robot controller**

(57) A robot controller which controls a process controlled variable of an operational tool mounted on a robot in synchronism with the robot motion. The position of each axis of the robot is detected by a sensor such as a position detector. In a calculating section, motion variables such as position P_n, velocity v_n and acceleration α_n of a tool center point (TCP) are detected from the respective positions of the robot axes. An ideal output (target value) of a sensor for detecting a controlled variable to be controlled in accordance with the motion state is determined in a calculating section. A sensor output is subtracted from the target value to determine a deviation. The deviation is multiplied by a proportional gain K to determine a manipulated variable. By using this manipulated variable, the process of an arc welding machine, sealing machine, or laser beam machine in which a tool is mounted on a distal end of a robot wrist is controlled. The target value is determined in accordance with the change of motion state of the robot, and feedback control is carried out so as to follow the target value so that uniform operation is achieved.

FIG. 1



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when peripheral equipment is an arc welding machine;
FIG. 3 is a block diagram of a process control section in accordance with one embodiment of the present invention when peripheral equipment is a sealing machine or a painting machine;
FIG. 4 is a block diagram of a process control section in accordance with one embodiment of the present invention when peripheral equipment is a laser beam machine;
FIG. 5 is a block diagram of a robot controller in the embodiment;
FIG. 6 is a flowchart for process control processing for peripheral equipment executed by a main processor of a robot controller in the embodiment;
FIG. 7 is a flowchart for processing in a process control section when the peripheral equipment is an arc welding;
FIG. 8 is a flowchart for processing in a process control section when the peripheral equipment is a sealing machine or a painting machine; and
FIG. 9 is a flowchart for processing in a process control section when the peripheral equipment is a laser beam machine.

[0013] FIG. 1 is a schematic diagram for explaining an operational principle of the present invention. In the present invention, the positions on robot axes are determined by various internal and external sensors of the robot, and a position P_n, a velocity v_n and an acceleration α_n of a TCP (tool center point; robot control point which is set at a center point of an end effector) are determined in a calculating section 2 based on the respective axes positions, and transferred to a process control loop 3 for controlling the process of an operational tool mounted on a distal end of a robot wrist.

[0014] In the process control loop 3, an ideal state of output of a sensor for detecting a controlled variable of a controlled object is determined in a sensor output ideal-state calculating section 3a, which constitutes supply control means, based on the position P_n, velocity v_n and acceleration α_n of the TCP as motion variables of the operational tool. In other words, a target value, which is an ideal value of the controlled variable detected by the sensor, is determined. Then, a deviation between the value in the ideal state (target value) and an actual value of the controlled variable detected by the sensor is obtained, and the deviation is multiplied by a proportional constant K (element 3b) to determine the manipulated variable, which is used as a control input for a process (3c) of the controlled object.

[0015] The above is a description of the principle of synchronous operation of the peripheral equipment with the robot in which the tool (peripheral equipment) mounted on the distal end of the robot requires process control in synchronism with the robot motion.

[0016] FIG. 5 is a block diagram of an essential portion of a robot controller for controlling the above-described peripheral equipment (tool) requiring the process control. A main processor 1, a memory 2 consisting of RAM, ROM, and nonvolatile memory (EEPROM etc.), an interface 3 for teaching operation panel, an interface 6 for external devices, and a servo control section 5 are connected to a bus 7. A teaching operation panel 4 is connected to the interface 3 for teaching operation panel.

[0017] A system program for supporting the basic functions of the robot and the robot controller is stored in the ROM of the memory 2. Also, a robot operation program taught for an specific application and associated set data is stored in the nonvolatile memory of the memory 2. The RAM of the memory 2 is used for temporary storage of data in various kinds of calculation processing performed by the processor 1.

[0018] The servo control section 5 has servo controllers 5_{a1} to 5_{an} (n: total number of robot axes, including the number of operational axes set to the tool mounted on the distal end of the robot wrist). Each of the servo controllers 5_{a1} to 5_{an} is composed of a processor, ROM, RAM, etc. to carry out position and speed loop control of a servomotor for driving each axis and further to carry out current loop control. The servo controller consists of a so-called digital servo controller which carries out loop control of position, speed and current by means of software. The output of the servo controller 5_{a1} to 5_{an} controls the servomotor M1 to Mn for each axis through a servo amplifier 5_{b1} to 5_{bn}. Although not shown in the figure, each of the servomotors M1 to Mn is provided with a position/speed detector so that the position and speed of each servomotor detected by the position/speed detector is fed back to each of the servo controllers 5_{a1} to 5_{an}. Also, the input/output interface 6 is connected with sensors provided on the robot and actuators and sensors of the peripheral equipment.

[0019] According to the present invention, process control for the processing shown in FIG. 1 is carried out by the robot controller having the above-described hardware constitution, with respect to the tool (peripheral equipment) mounted on the distal end of the robot wrist and requiring the process control in the peripheral equipments connected to the input/output interface 6.

[0020] FIG. 6 is a flowchart of processing, as shown in the schematic diagram of FIG. 1 showing the principle of operational, to be executed by the main processor 1 of the robot controller for each predetermined period to determine the manipulated variable to be outputted to the peripheral equipment requiring the process control.

[0021] First, an absolute position is read from a position detector for detecting the position on each axis of the robot, which is an internal sensor of the robot (Step S1). Based on the read axes position, generally called forward conversion

be increased. This means that the power of energy applied for welding must be changed in proportion to tool center point velocity v_n. Taking the power of applied energy as E, the welding current as I, and the resistance from the welding torch tip (tool tip) to a weld point of the object to be welded as R, $E = RI^2$. In order for the weld bead to be always kept constant even if the velocity v of the welding torch tip (tool center point) changes, the relationship expressed by the following equation (1) has only to hold.

$$E = RI^2 = K1 \cdot v_n \tag{1}$$

where, K1 is a proportional constant. From Eq. (1), the target value I_{cmd} of the welding current I, which is the controlled variable, is expressed as

$$I_{cmd} = (K1 \cdot v_n / R)^{1/2} \tag{2}$$

[0030] Also, since the resistance R from the welding torch tip to a weld point of the object to be welded is proportional to the distance between them, the resistance R is expressed as

$$R = K2 \cdot (\text{distance between welding torch tip and object}) \tag{3}$$

[0031] Thereupon, the target value I_{cmd} of the welding current can be determined from the above equations (2) and (3).

[0032] FIG. 7 is an essential portion of a flowchart for processing in each predetermined period of the main processor 1 which controls the welding current of the arc welding machine, which is the peripheral equipment.

[0033] In the processing for controlling the welding current of the arc welding machine, the processing in Step S6 is executed after the processing from Step S1 to Step S5 in FIG. 6 has been performed. In the control of the arc welding machine, the processing in Step S6 is replaced by the processing in Steps S6a1, S6a2 and S6a3 in FIG. 7, the processing in Step 7 is replaced by the processing in Step S7a, and the processing in Step S8 is replaced by the processing in Step S8a.

[0034] After the processing in Steps S1 to S5 is executed to determine the TCP position P_n, velocity v_n, and acceleration α_n in the present period, a robot motion command is first read by means of the taught operational program, and a commanded position P_p of TCP is determined by forward conversion (Step S6a1). If the taught operational program has been produced at the TCP position P_p on the reference orthogonal coordinate system, the processing of forward conversion need not be performed, and the read data is data of the TCP position P_p.

[0035] Next, a size G_n of a gap between the TCP and a weld point position is determined from the commanded value P_p of TCP position and the present position P_n. Specifically, the size G_n of a gap between the weld torch tip position and the weld point position is determined. In this embodiment, a weld line of the object lies on the X-Y plane on the reference orthogonal coordinate system, and the welding torch is disposed in the plus direction of Z axis above the plane on which the weld line of the object lies, so that a position which is apart from the welding torch tip (TCP) by a predetermined gap size G_0 in the plus direction of Z axis is taught as the weld line. Therefore, the size G_n of the gap in the present period is determined as follows: The position P_p commanded by the taught operational program is subtracted from the present position P_n of TCP to determine a position deviation between the present position P_n and the position P_p commanded by the taught operational program, and the size G_0 of the gap at the time of teaching is added to this position deviation (Step S6a2).

$$G_n = P_n - P_p + G_0 \tag{4}$$

[0036] By using the gap G_n thus obtained, the processing of Eq. (3) is performed to determine the resistance R, and further the processing of Eq. (2) is performed to determine the commanded current I_{cmd} as the target welding current (Step S6a3). The measured value I_f of welding current fed back from the welding machine is read via the input/output interface 6 (Step S7a), and a value obtained by subtracting the fed back current I_f from the commanded current I_{cmd} is multiplied by the proportional gain K to obtain the voltage command V_{cmd} (= $K \cdot (I_{cmd} - I_f)$) and give it to the welding machine (Step S8a). Thereby, the processing in the present process period is completed. Subsequently, for each period, the processing in Steps S1 to S5 in FIG. 6 and Steps S6a1, S6a2, S6a3, S7a and S8a in FIG. 7 is executed to change the welding current of the welding machine according to the movement velocity of the welding torch (tool),

where, k1, k2 and K1 are constants.

[0043] If the driving current I of the laser oscillator is changed according to the velocity v_n of the laser beam machining head so that the above equation (6) holds, the energy applied per unit movement distance is made uniform even if the velocity changes, so that laser machining of uniform quality can be achieved.

[0044] FIG. 4 is a block diagram of the process control section 3 for a laser beam machine. In the sensor output ideal state calculating section 3Ca of the laser beam machine, a target current command I_{cmd} is determined by performing the calculation in Eq. (6) using the tool center point velocity (movement velocity of nozzle tip of the laser beam machining head). A fed back value I_f of driving current of the laser oscillator, which is detected by a sensor, is subtracted from the target current command I_{cmd} to determine the current deviation. This current deviation is multiplied by the proportional gain K (element 3Cb) to determine a voltage command (manipulated variable) V_{cmd} of the laser oscillator, and the laser oscillator 3 Cc is driven by this voltage command V_{cmd}.

[0045] FIG. 9 is a flowchart for processing executed in place of Steps S6, S7 and S8 in FIG. 6 in the case where the peripheral equipment to be process controlled is a laser beam machine.

[0046] The main processor 1 of the robot controller performs the processing in Steps S1 to S5 shown in FIG. 6 to determine the velocity v_n of nozzle tip of the laser beam machine, and performs the calculation of Eq. (6) using this velocity to determine the target current command I_{cmd} (Step S6c). Then, a value obtained by subtracting the fed back value I_f of a measured value of driving current of the laser oscillator, which is measured by a sensor, from the target current command I_{cmd} is multiplied by the proportional gain K to determine the voltage command V_{cmd} (= $K \cdot (I_{cmd} - If)$) to the laser oscillator as the manipulated variable, and the voltage command V_{cmd} is given to the laser oscillator via the external input/output interface 6 (Steps S7c and S8c).

[0047] Subsequently, the processing in Steps S1 to S5 and Steps S6c, S7c and S8c is executed for each predetermined period. The target commanded current I_{cmd} is changed according to the movement velocity of the laser beam machining head, and feedback control is carried out so that the driving current value of the laser oscillator, which is detected by the sensor, agrees with the target commanded current I_{cmd}. Therefore, even if the movement velocity of the laser beam machining head changes, energy per unit movement distance applied by the laser beam machine is made constant, so that laser beam machining such as cutting of uniform quality can be achieved.

[0048] In the peripheral equipment which applies a substance or energy to an object through the operational tool mounted on the distal end of the robot wrist, even if the state of robot changes, the robot controller carries out the process control for applying the substance or energy according to the change, so that the substance or energy can always be applied uniformly. Thereby, machining of high quality can be achieved.

Claims

1. A robot controller comprising:

   motion control means for moving an operational tool mounted on a robot with respect to an object;
   supply means for supplying energy to be applied to the object through said operational tool;
   supply control means for issuing a supply command to said supply means, said supply command being determined based on motion variable of said operational tool in motion obtained by said motion control means; and
   means for feeding back a parameter representing power of said energy supplied through said operational tool to alter said supply command based on the fed back parameter.

2. A robot controller for arc welding operation according to claim 1, wherein said motion variable is speed of a control point of the robot relative to the object, said supply means is power source for supplying welding current and said parameter is the welding current.

3. A robot controller for laser welding operation according to claim 1, wherein said operational variable is speed of a control point of the robot with respect to the object, said supplying means is a laser oscillator for supplying laser beam and said parameter is excitation current of said laser oscillator.

4. A robot controller for controlling a robot comprising:

   motion control means for moving an operational tool with respect to an object;
   supply means for supplying energy to an operational substance to be fused so as to apply the fused operational substance to the object through said operational tool;
   supply control means for issuing a supply command to said supply means, said supply command being de-

FIG. 1

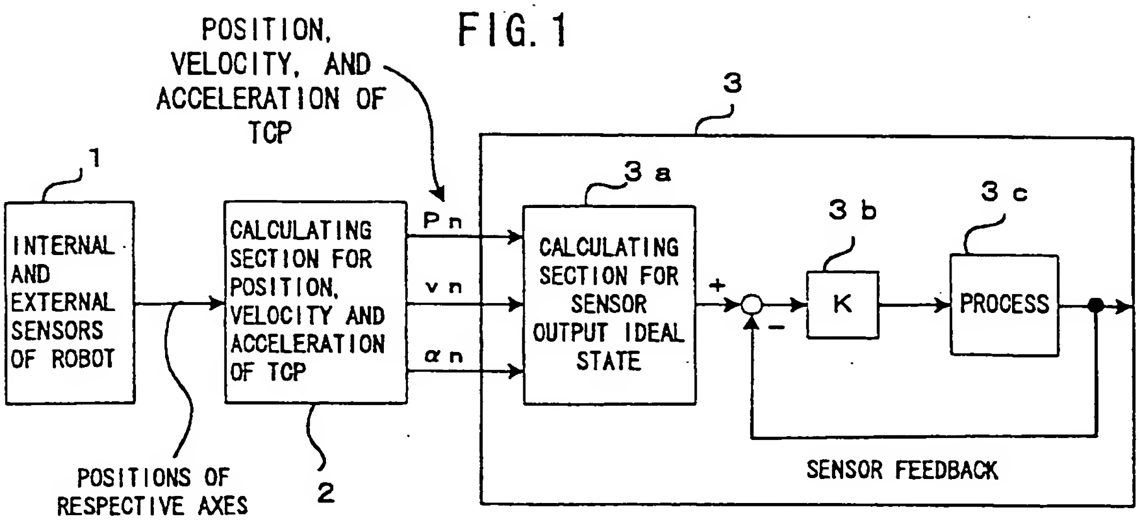
POSITION, VELOCITY, AND ACCELERATION OF TCP
3
1
3 a
3 b
3 c
INTERNAL AND EXTERNAL SENSORS OF ROBOT
CALCULATING SECTION FOR POSITION, VELOCITY AND ACCELERATION OF TCP
P n
v n
α n
CALCULATING SECTION FOR SENSOR OUTPUT IDEAL STATE
+
−
K
PROCESS
SENSOR FEEDBACK
POSITIONS OF RESPECTIVE AXES
2

FIG. 2

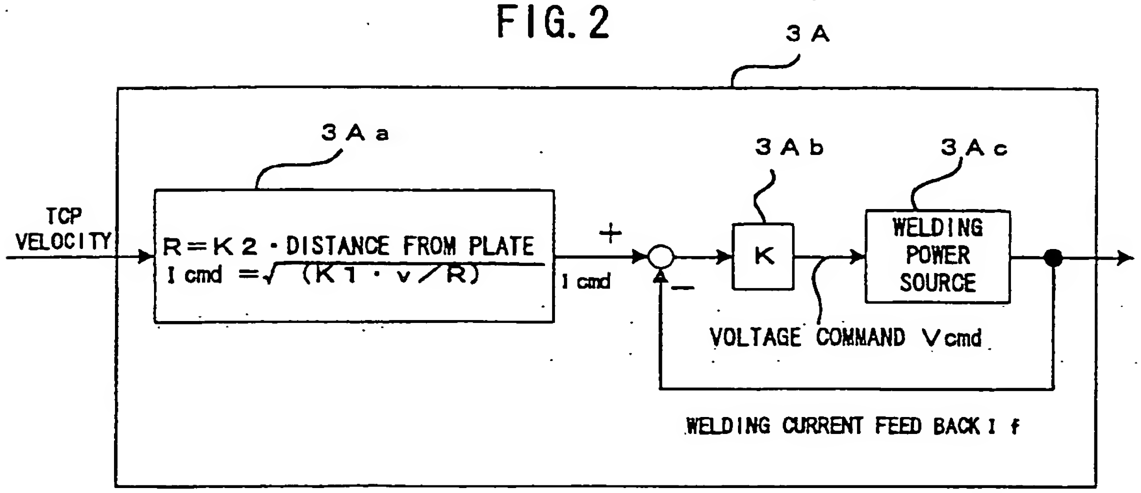
3 A
3 A a
3 A b
3 A c
TCP VELOCITY
R = K 2 · DISTANCE FROM PLATE
I cmd = √(K 1 · v / R)
I cmd
+
−
K
WELDING POWER SOURCE
VOLTAGE COMMAND V cmd
WELDING CURRENT FEED BACK I f

FIG. 5

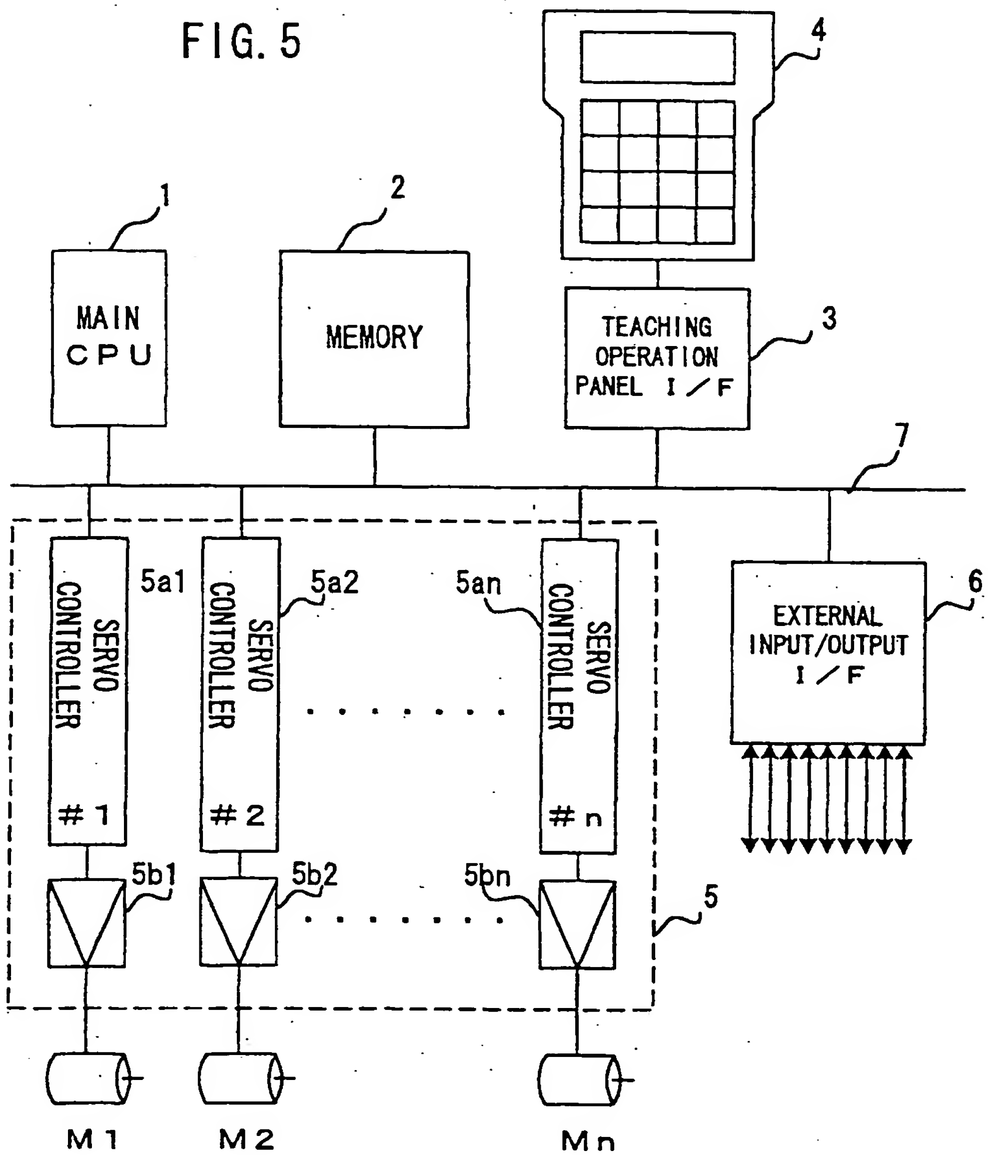
4
1
2
MAIN CPU
MEMORY
TEACHING OPERATION PANEL I/F
3
7
SERVO CONTROLLER #1
5a1
SERVO CONTROLLER #2
5a2
5an
SERVO CONTROLLER #n
EXTERNAL INPUT/OUTPUT I/F
6
5b1
5b2
5bn
5
M1
M2
Mn

FIG. 7

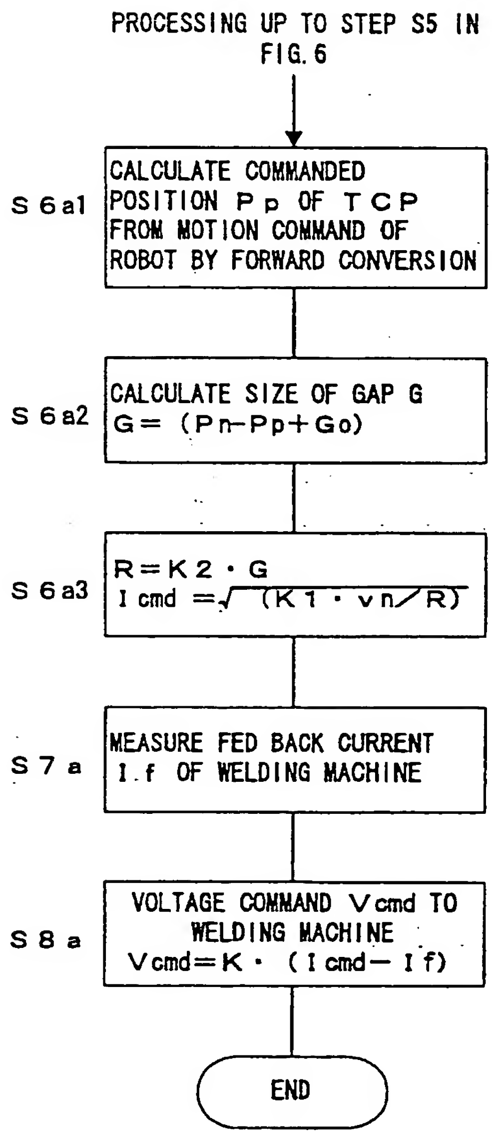
PROCESSING UP TO STEP S5 IN FIG. 6
S 6 a1
CALCULATE COMMANDED POSITION Pp OF TCP FROM MOTION COMMAND OF ROBOT BY FORWARD CONVERSION
S 6 a2
CALCULATE SIZE OF GAP G
G= (Pn−Pp+Go)
S 6 a3
R=K2・G
I cmd =√ (K1・vn/R)
S 7 a
MEASURE FED BACK CURRENT I f OF WELDING MACHINE
S 8 a
VOLTAGE COMMAND Vcmd TO WELDING MACHINE
Vcmd=K・ (I cmd− I f)
END

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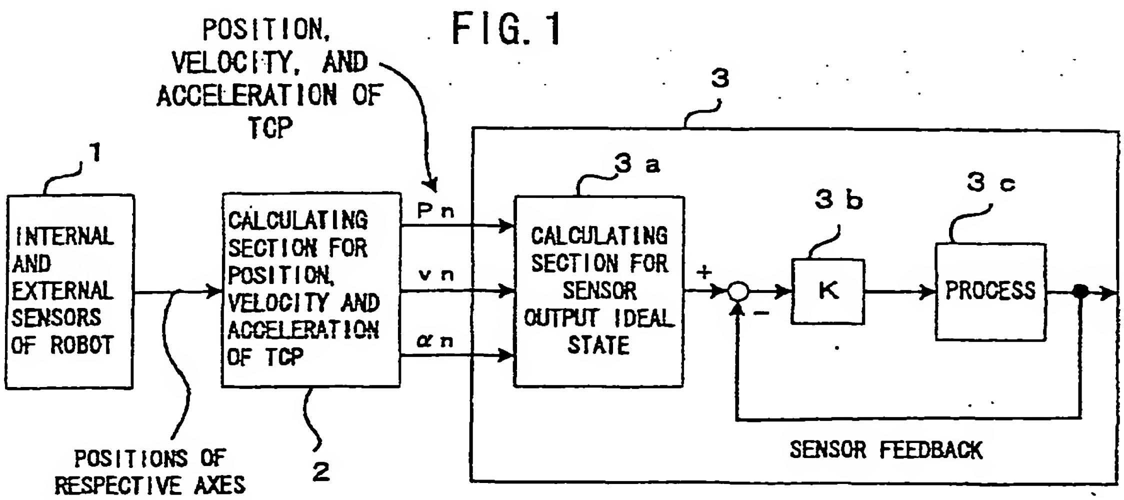
FIG. 1



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